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Electromagnetic properties of carbon nanotube reinforced concrete composites for frequency selective shielding structures

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HIGHLIGHTS

- Carbon nanotube reinforced concretes were characterized in microwave bands.
- Shielding effectiveness was evaluated by reverberation chamber system.
- Frequency selective absorber made of reinforced concretes was designed.
- Particle swarm optimization algorithm was used in the absorber design.

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ABSTRACT

Carbon nanotube reinforced concrete composites (RCC) were characterized in microwave bands currently employed in wireless telecommunication systems. Dielectric permittivity was retrieved by waveguide method and adopted to compute shielding effectiveness of RCC structures having different thickness/-filler content. The shielding was also evaluated by reverberation chamber set up; theoretical calculations and measured values are in close agreement, thus testifying to the procedure reliability. Finally, a frequency selective absorber made of RCC layers was designed with the aid of a numerical optimization tool (particle swarm algorithm); the discussion of results is supported by a finite element method analysis of the layered structure.

1. Introduction

The presence of many electromagnetic interference (EMI) source signals, sometimes overlapped in the frequency spectrum, represents an issue in TLC, military, and medical applications [1–3]. In this context, many researchers are nowadays focused in developing materials and structures having EMI shielding effectiveness (SE) capability [4–8]. One common concern is related to the possibility to reduce the amount of interference coming from the outdoor to indoor of buildings. This task can be achieved by means of special glass in windows [9,10]; on the other hand, even if the SE of walls is typically >10 dB [11–17], the sidewalls shielding capability remains open. In a previous paper [18] the SE of concrete composites was analyzed in the frequency band 0.75–1.12 GHz by using waveguide. Whit respect to [18] the frequency band was extended to a new one in a higher range (1.7–2.6 GHz), which is of interest in telecommunication systems. Moreover, the measurements of SE by using a reverberation chamber were introduced. By this way a reliable electromagnetic characterization of realistic multipath environments is allowed, as well as the comparison between the numerical simulations and the measurements. Finally, the concept of electromagnetic tunable RCC was firstly presented.

Tunable systems able to be more effective in a specific frequency band with respect to others have not been proposed so far in literature [19–43]. Such feature, on the contrary, could result useful in a real scenario: in fact, beside the capability of

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having high SE on extended frequency bands, other applications could require materials able to allow the EM waves propagation preferably at certain frequencies, while attenuating elsewhere. For example, one could search for materials able to propagate certain cellular phone frequencies in the band up to 2100 MHz and contemporary attenuate WiFi frequencies above 2300 MHz. In this paper both the possibilities are explored. In particular, Pozzolan concrete composites are reinforced with multiwall carbon nanotube (MWCNT) in different weight percentages. Estimation of electric permittivity is performed via waveguide method in the 0.75–1.12 GHz and 1.7–2.6 GHz frequency ranges, and then used to compute the SE as a function of structure thickness and MWCNT concentration. The obtained values are then compared to those directly observed by analyzing the samples in a reverberation chamber set up, thus checking the agreement between computed and measured SE. Finally, the possibility to obtain a frequency selective reinforced concrete composite (FSRCC) is explored: with such an aim, a multilayered structure is designed with the aid of the particle swarm optimization (PSO) algorithm and analyzed via numerical finite element method (FEM). The paper is organized as follows: the next section describes materials and methods, then the measurements and the procedure of optimization are reported, in the final section the results are discussed by referring to a practical application of the proposed solution.

2. Materials and methods

2.1. Sample manufacturing

Reinforced concrete composite samples have been manufactured by imitating the conventional technique adopted for concrete materials manufacturing, with a view toward a scaling-up background. In this perspective, large amount of MWCNT are needed and, consequently, employing industrial-grade MWCNT powder is advisable for low-cost processing development. The used MWCNTs have average diameter 9.5 nm, average length 1.5 µm, carbon purity 90%, metal oxide 10%, surface area 250–300 m^2/g. About concrete, the employed material is commercially available Pozzolan-cement. The weight percentage of MWCNT with respect to dry cement powder is 0 (naked concrete), 1.0, and 3.0 wt%; the corresponding materials are respectively labeled M1, M2, and M3. In Fig. 1 the raw materials and the RCC preparation stages are shown. About 5 kg of concrete and 150 g of MWCNT powder have been used for the preparation of M3 material, and that (due to the strikingly high MWCNT surface area) both amount take almost the same volume. The mixtures are blended by means of an electric power mortar (rotation velocity 0–690 rpm/min), thus avoiding any sophisticated MWCNT-based composite treatment (ultrasound mixing, nanoparticles purification, chemical functionalization, etc.). First, Pozzolan-cement are pre-mixed with a fixed amount of water; the MWCNTs are then englobed and homogenized within the concrete pulp, and the compound is blended for about 4 h by further additions of water. To complete the dispersion of MWCNT at 3wt% a total amount of water about four time greater than that used for the preparation of naked concrete is necessary. The MWCNTs are poured into the mixture step by step: in Fig. 1a picture show the MWCNT addition time line, whereas in Fig. 1b the final homogenous composite is shown, its unusual brown color denoting the presence of carbon nanoparticles. The mixtures are poured in the different sample holders and dry in environmental conditions for two months. The sample holders are based on WR975 (~25 × 12 cm^2) and WR430 (~11 × 5.5 cm^2) waveguide adapter type. About the frame used as sample holder for the SE measurement by reverberation chamber, a metallic sheath has been applied around the internal sidewall to improve the electric contact between material and holder (see Fig. 2); in fact, even micro-airgaps are able to affect the SE measurements due to microwave leakages [44–47].

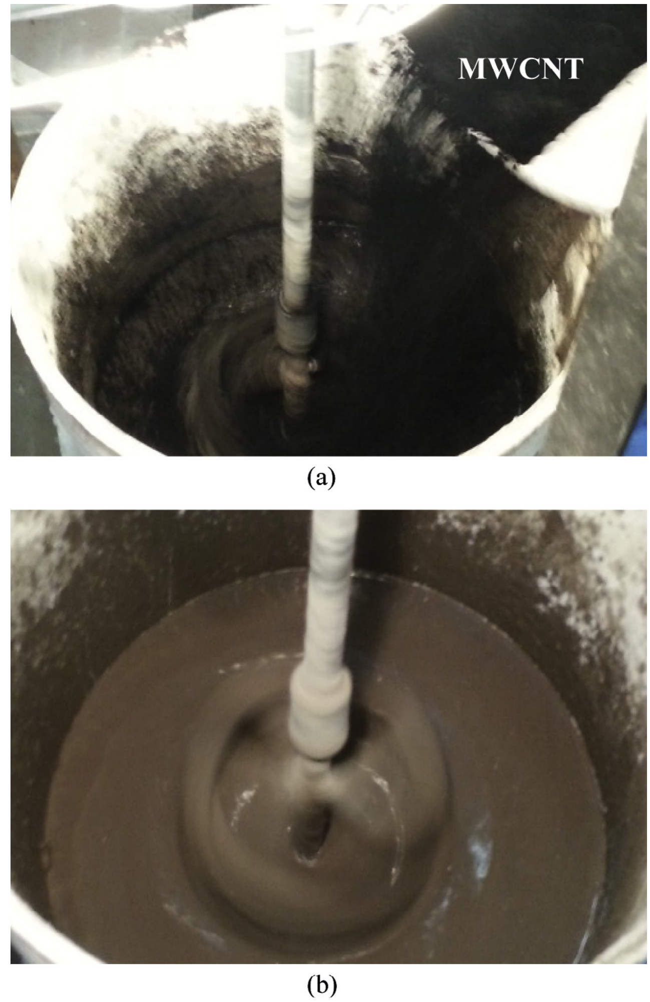

Fig. 1. Concrete and MWCNT composite manufacturing: (a) MWCNT dispersion steps, (b) concrete composite after 4 h of mechanical homogenization.

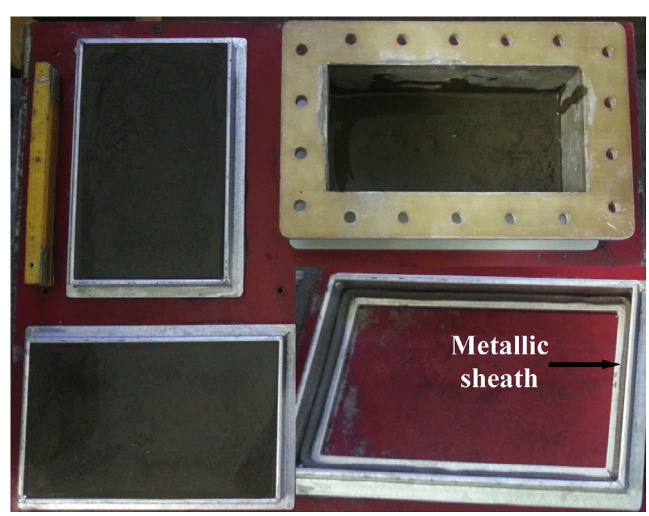

Fig. 2. Holders filled with RCC 3 cm thick samples for reverberation chamber characterization and waveguide holder adapter type WR975. The metallic sheath is visible in the empty sample holders for the reverberation chamber.